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CABLE SHEATHS AND WATER PERMEABILITY

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Gordon F. Todd

One of the oldest enemies of wire and cable is moisture. When moisture successfully attacks an electric cable, the system design can be seriously affected. By penetrating into the insulation or into interstices, moisture can impair the electrical characteristics of capacitance, power factor, insulation resistance and dielectric strength. Occasionally, because of moisture, a cable will short-circuit to ground, accompanied by a shower of molten copper, soot, and irate personnel.

Workers in the cable industry have striven to reduce the moisture hazard by improving the moisture resistance of insulations, and by improving splicing methods. We have seen large quantities of plastic and rubber insulations perform very well in moist and wet locations. Critical cables have been covered by lead sheaths, and the sheaths have been covered by protective coverings of their own.

And yet we ask, "Are rubber and plastic sheaths capable of great water resistance? What are the standards of reference? What is the validity of the test methods? What is the effect of temperature and wall thickness upon the water resistance of a protective sheath?"

The work described in this paper was done in order to throw light on these questions. As the result of it we have, first of all, established considerable data bearing upon the performance of a number of different materials in water. We have found a short test to be effective in measuring water penetration, and have confirmed the findings by a series of observations made with cables. We have related temperature and wall thickness with the rate of water penetration. Finally, we have been able to find two materials of better than average suitability for situations where considerable water resistance is needed, but where lead sheath is objectionable.

For many years, one popular method of studying the water resistance of rubber and plastic insulations has been a water absorption test. It has been found to be convenient, involving simple equipment. The cable industry has come to regard it as having considerable value as a supplement to electrical water absorption tests. The test is based simply upon finding the water absorbed per square in^{ch} of surface.

With the help of the water absorption test, such excellent insulations as RW, RH-RW, TW, and Butyl were developed. It became possible to achieve good service in wet locations without the protection of lead sheaths. In many cases, rubber and plastic sheaths were made possible, by reason of the improved resistance of insulations to water.

It was only natural that rubber and plastic sheaths were tested for water absorption by the classic test, and relative merit ascribed. However, it has seemed to us that where protective coverings are concerned, a new set of conditions is introduced. Here, the problem is not primarily the maintenance of electrical properties of the sheath in question, but rather the ability of the material to serve as a water barrier. A good sheath should simply keep water out.

It seemed to us that a more natural way to study the barrier characteristics of a cable sheath was by means of a suitable water permeability test. We were interested to know how such data correlated with the classic water absorption test. We sought a check method whereby we could verify laboratory specimen tests with cable tests.

A program of study of 22 rubber and plastic compounds was undertaken. These compounds represented materials which were in commercial use, some for insulating, and others for cable sheathing purposes. Each material was subjected to three groups of tests:

1. Water absorption, IPCEA method.
2. Water permeability, Du Pont method.
3. Water penetration of cable sheath, Collyer method.

The first method, the classic water absorption test, was made with uniformly molded sheets .070" thick. Specimens measuring 1"x4" were tested by the method described in the cable industry's IPCEA Specification S-19-81, Appendix N. The tests were done in duplicate. Results are expressed as grams absorbed per square inch of surface. The meaning of the results is the relative tendency to soak up water.

The second method, water permeability, was made with uniformly molded discs, .030" thick. These 3" diaphragms were tested by the Du Pont method, based upon measuring the rate of water transmission directly through the membrane. The actual testing of discs, prepared in the Collyer Laboratory, was very accurately done by the Du Pont Company in triplicate, at request. Results are expressed as milligrams per square inch per day per 1-mil thickness. The meaning of the results is the relative rate of permeability.

The third method was much more elaborate. It consisted of studying cable sheaths immersed in water. Wall thicknesses of .050" and .080" were compared, as were immersion temperatures of 50°C and 70°C. The test cables themselves consisted of 3' lengths of identical 2-cdr. #18 jute-filled cable, insulated with a GRS rubber compound, and jacketed uniformly with each material. The immersion studies were carried out for 150 days, and were extended to 300 days for some groups. The water penetration was detected by studying mutual capacitance as time progressed, it having been found that the presence of moisture in the jute-filled cable spaces would rapidly affect mutual capacitance. Data was recorded as mmf. and time, and

was later converted to % change and so plotted. The number of cable specimens totaled 88, representing 2 walls and 2 temperatures. These specimen cables were all prepared under strict control in the Collyer Laboratory. Equipment considerations limited observations to a single specimen for each case. The meaning of the results is speed of water penetration through the cable sheath.

We present several figures with which we describe our work:

Figure #1 shows the form of specimens used in each test.

Figure #2 shows the immersion of the cables.

Figure #3 shows cable samples after immersion for 150 days at 70°C. Note deterioration of one sample having .050" wall.

Figure #4 shows several typical curves drawn from cable observations. We cannot show all 88. Note the change of slope as jute fillers become saturated, as heat aging takes hold, and as water absorption equilibrium becomes established. Analysis of these curves was done by tabulating % change in mutual capacitance with time. It was separately determined that instantaneous saturation of the jute filler causes approximately 50% increase in mutual capacitance.

Table #1 shows averaged data for the Water Absorption and the Water Permeability tests. The materials are arranged in the order of their water absorption. Inspection of this data reveals no dependable correlation between Water Absorption and Water Permeability tests.

Table #2 shows a comparison of the Water Permeability data with one of the Cable Penetration test groups. This time the order is rearranged in terms of relative water permeability. Inspection of the data reveals a strong tendency toward correlation between the two testing methods. We believe that this agreement between elaborate tests of cables and simple tests of discs lends validity to the Water Permeability procedure, and establishes it as a valuable tool for evaluating cable sheaths.

Table #3 shows an analysis of all of the Cable Penetration test groups. Materials are arranged in order of overall % increase in mutual capacitance in 10 days. Some valuable information is evident:

1. Some materials have assumed a new order of effectiveness, not apparent where the Water Absorption test is used.
2. The order of effectiveness of each group is nearly the same, even though walls and temperature vary.

3. The overall order of effectiveness is nearly the same as the order based on the Water Permeability of discs. Each method places a given material in the same general category.
4. Increased wall thickness retards water penetration of sheaths. However, increased walls fail to make a top-notch material from a fair one.
5. Increased immersion temperature increases rate of water penetration of sheaths. This tendency can be counteracted only slightly by increasing wall thickness.

Table #4 shows another analysis of all of the Cable Penetration test groups. The % increase in mutual capacitance in 50 days is shown. By this time the slope of many of the curves had changed from a sharp rise to a shape indicating equilibrium, complicated by secondary water absorption and heat aging effects.

Table #5 shows a final analysis of all of the Cable Penetration test groups. The % increase in mutual capacitance is shown for 150 days for two groups, and 300 days for the other two. We believe the chief significance is the demonstration of the long-term barrier effect possessed by some materials.

SUMMARY

The degree to which a cable sheath material can protect the interior of a cable from moisture may be determined by simple water permeability tests. Water permeability tests are more reliable for this purpose than water absorption tests, and agree quite well with elaborate cable soaking tests carried out for many months at elevated temperature.

Extensive cable immersion data relates 22 materials as follows:

Best, Very Good	Butyl Compound
Very Good	Polyethylene
Good	Butyl-Neoprene Laminate
Moderate to Fair	Black Neoprene, CV Type Sheath Black Neoprene, Lead Cure Type Sheath Hypalon Compound Low Water Absorbing Neoprene Sheath White Neoprene Sheath GRS Black Sheath Black Ozone Resisting Neoprene Sheath Oil Base Compound GRS Type RH-RW Compound Hycar Oil Resistant Compound
Fair to Poor	Natural Rubber 60% Black Sheath Hycar Oil & Water Res't Compound PVC Low Water Absorbing Sheath PVC Type TW, 90°C Compound PVC Semi-Rigid Sheath Natural Rubber 40% Compound PVC -50°C, Low Water Abs. Sheath PVC -50°C, Gen'l Purpose Sheath
Very Poor	Silicone Rubber 125°C Compound

No rubber or plastic material was found to possess total water barrier capability.

* * *
Acknowledgement is made of the outstanding sample preparation and testing work done by colleagues William E. Garne and Joseph L. Jacinto. We wish also to thank the Du Pont Company for use of its procedures and testing services, and the B. F. Goodrich Company for technical aid.

FIGURE 1

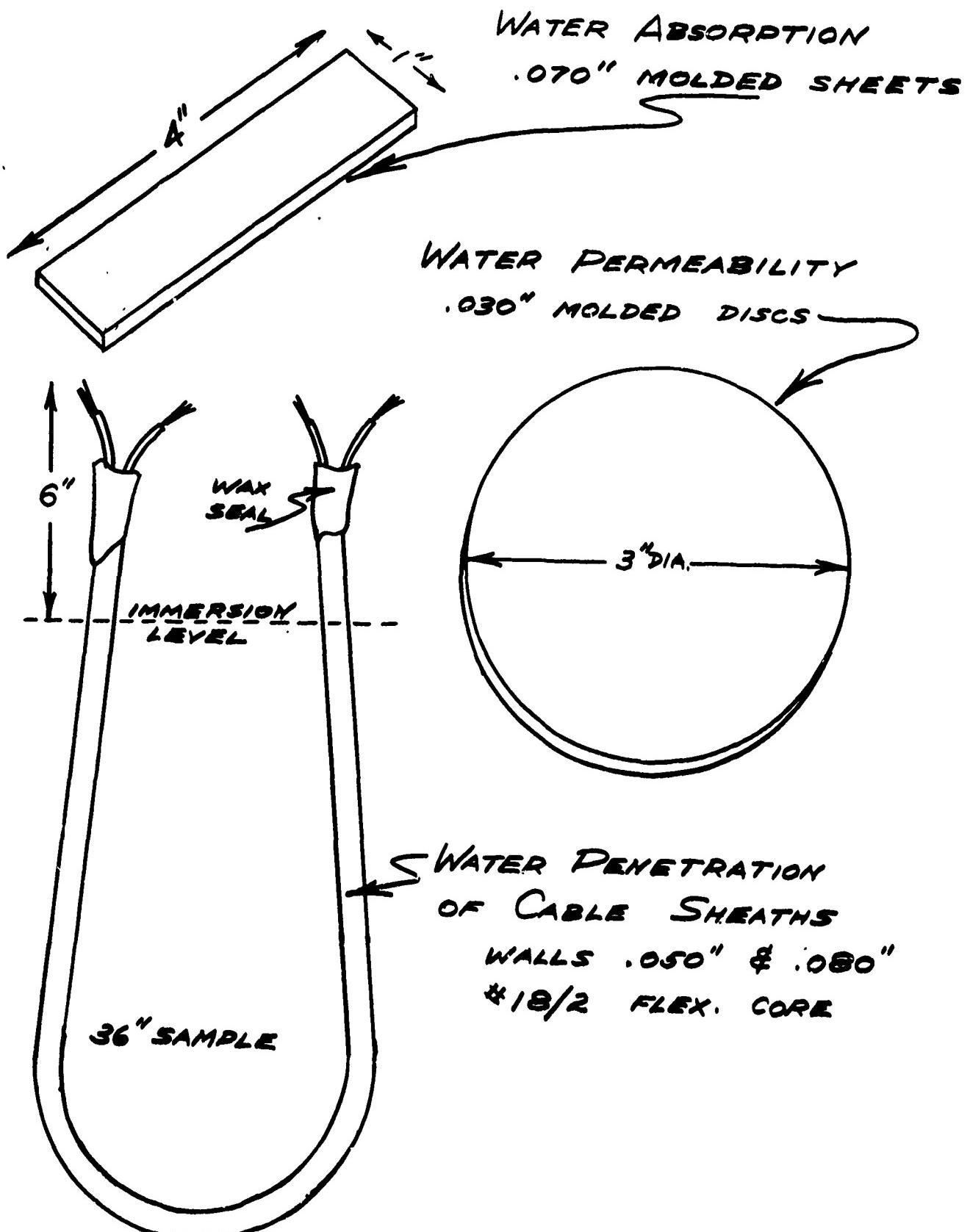


FIGURE 2

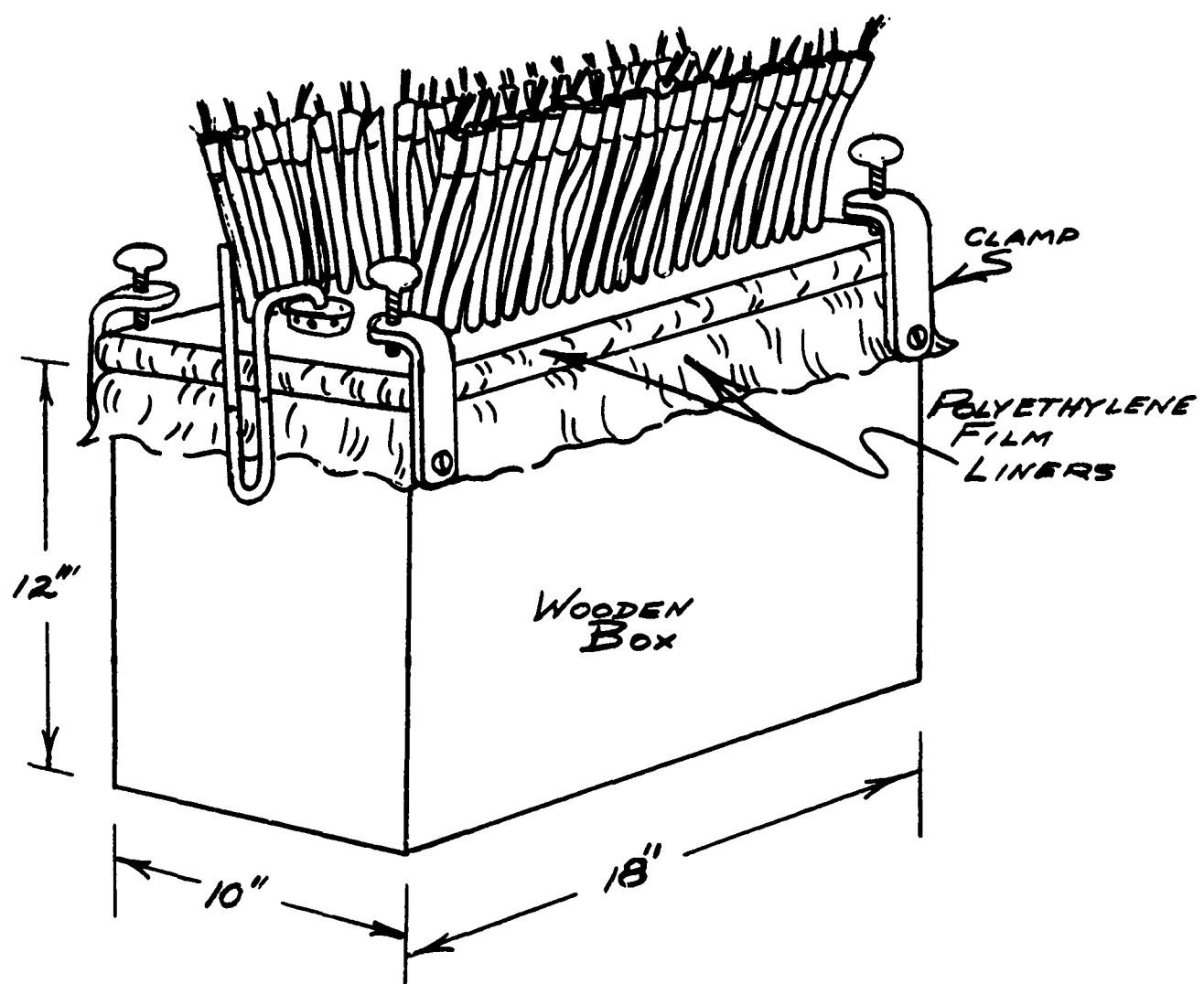


FIGURE 3

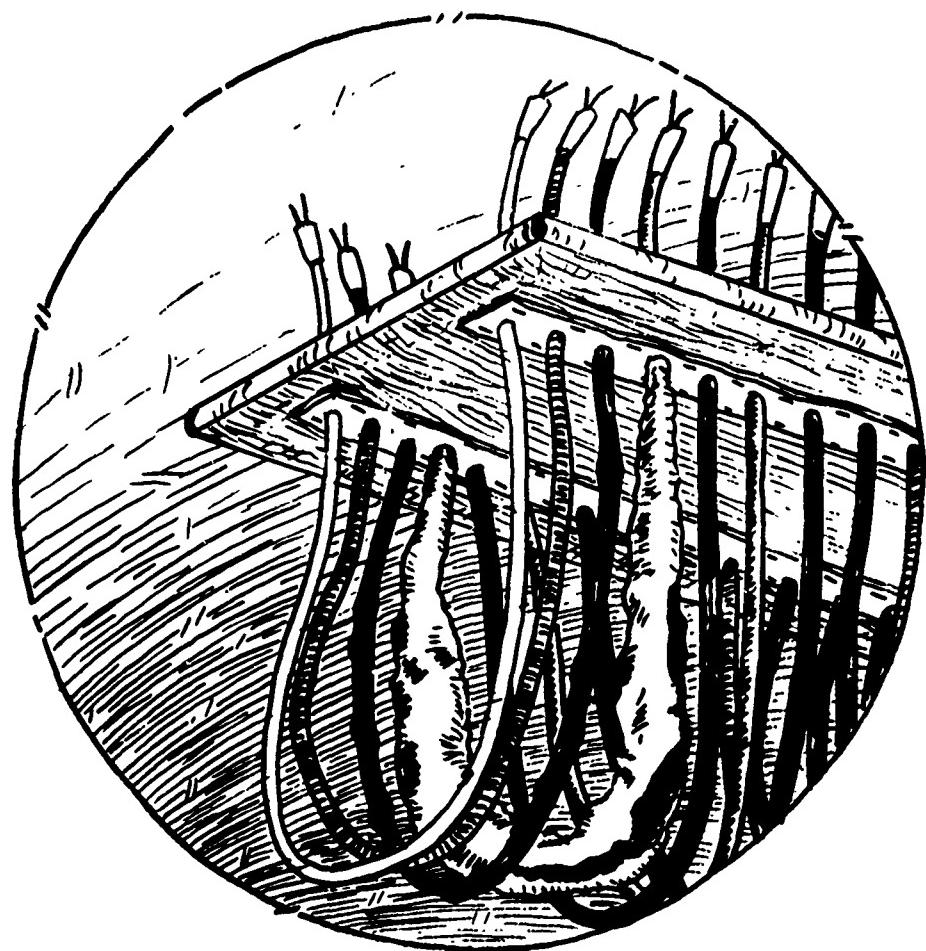


FIGURE 4

TYPICAL CURVES FOR .080" SHEATHS IMMERSED AT 70°C
ILLUSTRATING CHANGE IN MUTUAL CAPACITY WITH TIME

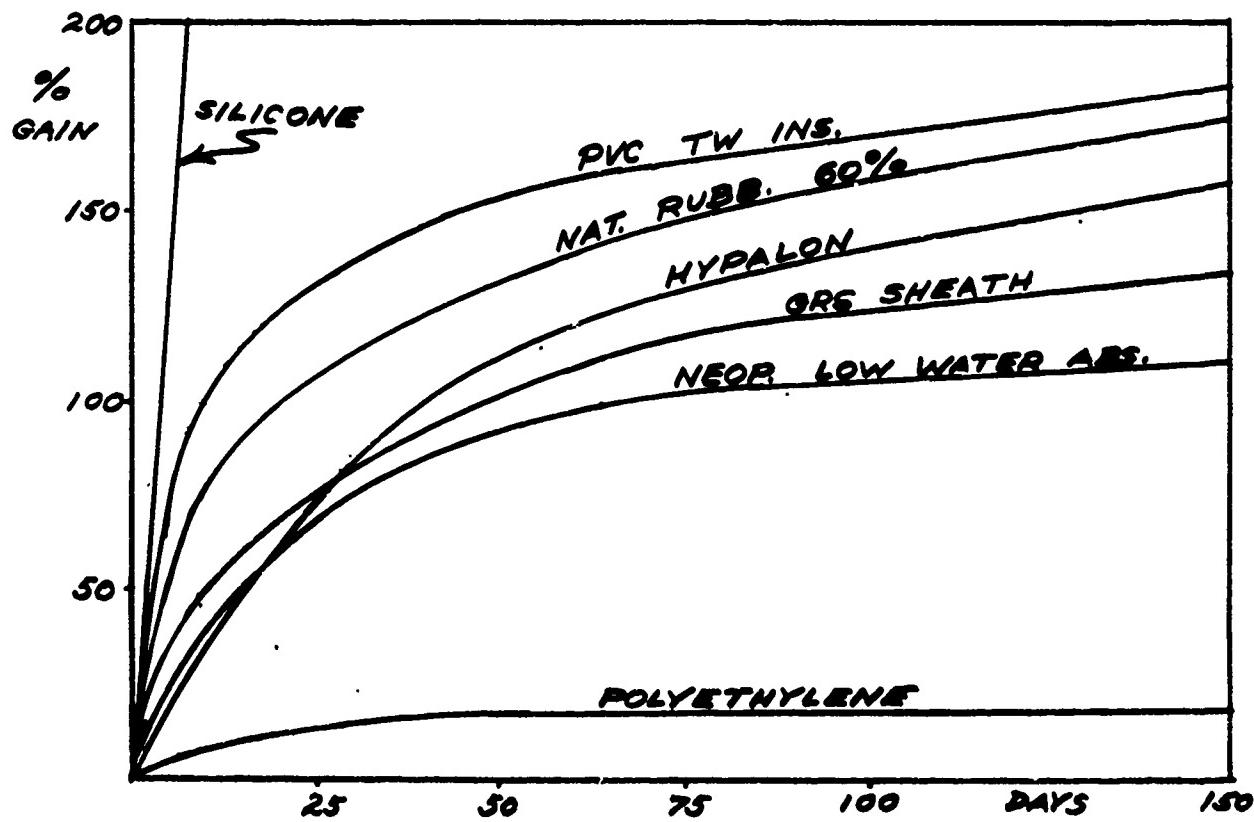
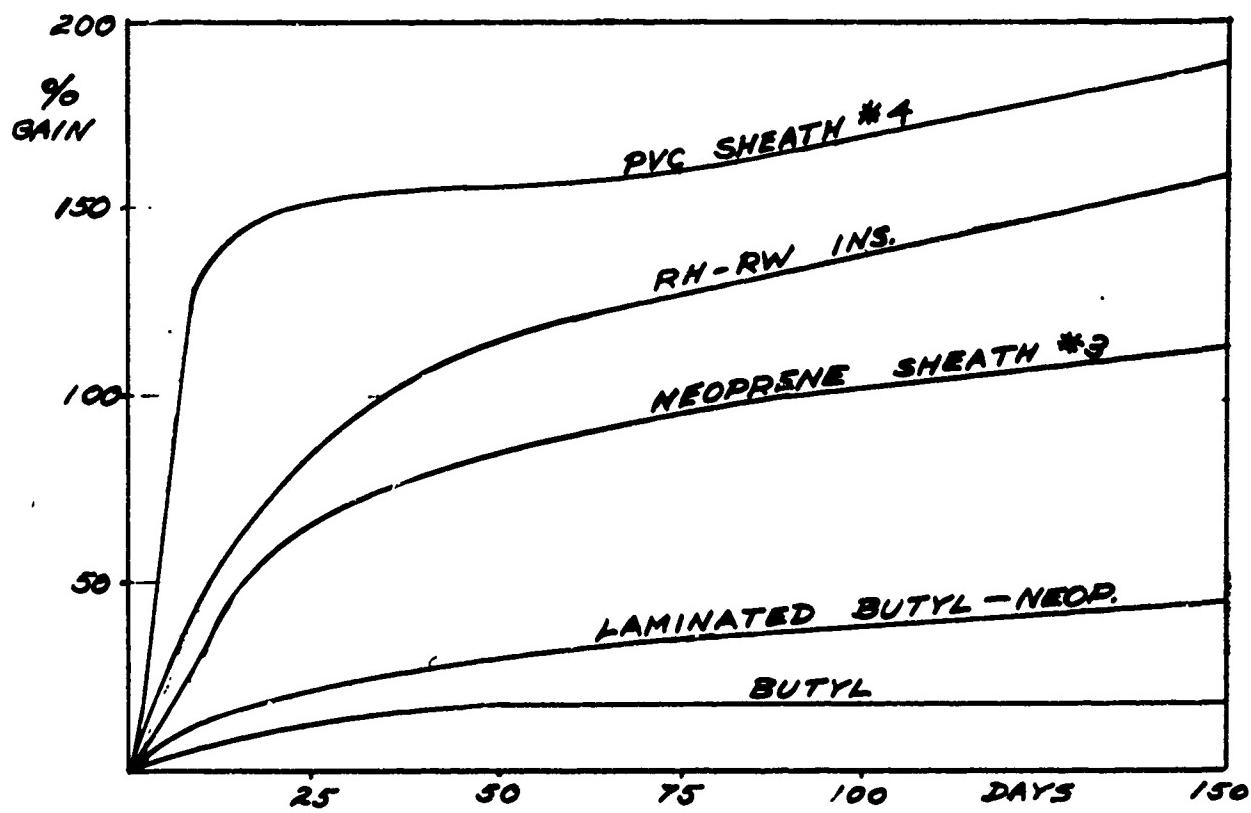


TABLE 1

	<u>WATER ABSORPTION OF STRIPS</u>	<u>WATER PERMEABILITY OF DISCS</u>
POLYETHYLENE	.5 mg.	2 mg.
BUTYL POWER INSULATION	4	.6
RH-RW INSULATION (GRS)	7	17
PVC SHEATH #1	9	25
PVC TW 90°C INSULATION	10	23
PVC SHEATH #2	11	47
PVC SEMI-RIGID SHEATH #3	15	32
SILICONE 125°C INSULATION	15	410
PVC SHEATH #4	16	58
HYPALON SHEATH	18	13
GRS SHEATH	18	19
HYCAR SHEATH #1	20	82
OIL BASE POWER INSULATION	21	18
NEOP. LOW WATER ABS. SHEATH	22	12
NAT. RUBBER 40% INS.	24	32
NAT. RUBBER 60% SHEATH	29	31
HYCAR SHEATH #2	30	65
LAMINATED BUTYL-NEOPRENE	57	3
NEOPRENE SHEATH #2	70	12
NEOPRENE SHEATH #3	71	8
NEOPRENE SHEATH #4	91	9
NEOPRENE SHEATH #5	99	8
TERMS	Mg. / Sq. in.	Mg./Sq. In./Day/Mil.

TABLE 2

	WATER PERMEABILITY OF DISCS	WATER PENETRATION OF .050" WALL CABLE SHEATHS
BUTYL POWER INSULATION	.6 mg.	1 %
POLYETHYLENE	2	1
LAMINATED BUTYL-NEOPRENE	3	5
NEOPRENE SHEATH #3	8	10
NEOPRENE SHEATH #5	8	18
NEOPRENE SHEATH #4	9	12
NEOPRENE SHEATH #2	12	12
NEOP. LOW WATER ABS. SHEATH	12	17
HYPALON SHEATH	13	9
RH-RW INSULATION (GRS)	17	17
OIL BASE POWER INSULATION	18	16
GRS SHEATH	19	14
PVC TW 90°C INSULATION	23	35
PVC SHEATH #1	25	36
NAT. RUBBER 60% SHEATH	31	35
NAT. RUBBER 40% INS.	32	40
PVC SEMI-RIGID SHEATH #3	32	33
PVC SHEATH #2	47	80
PVC SHEATH #4	58	96
HYCAR SHEATH #2	65	68
HYCAR SHEATH #1	82	84
SILICONE 125°C INS.	410	187
TERMS	Mg./Sq. In./Day/Mil.	% Mutual cap. gain in 10 days @ 50°C

TABLE 3

10 DAY

WATER PENETRATION OF CABLE SHEATHS

	<u>50°C .050"</u>	<u>50°C .080"</u>	<u>70°C .050"</u>	<u>70°C .080"</u>
BUTYL POWER INSULATION	1 %	1 %	10 %	5 %
POLYETHYLENE	1	1	10	5
LAMINATED BUTYL-NEOPRENE	5	2	18	10
NEOPRENE SHEATH #2	12	6	40	20
NEOPRENE SHEATH #3	10	5	49	22
HYPALON	9	8	44	25
NEOPRENE SHEATH #4	12	7	60	31
NEOP. LOW WATER ABS. SHEATH	17	8	65	38
GRS SHEATH	14	11	70	47
NEOPRENE SHEATH #5	18	10	70	35
RH-RW INSULATION	17	9	77	44
OIL BASE POWER INSULATION	16	12	79	52
NAT. RUBBER 60% SHEATH	35	15	110	74
PVC TW 90°C INSULATION	35	7	133	103
NAT. RUBBER 40% INSULATION	40	17	120	86
PVC SEMI-RIGID SHEATH #3	33	18	127	105
PVC SHEATH #1	36	21	126	106
HYCAR SHEATH #2	68	54	110	107
HYCAR SHEATH #1	84	54	112	111
PVC SHEATH #2	80	52	153	124
PVC SHEATH #4	96	67	155	131
SILICONE 125°C INS.	187	168	212	208

DATA IS EXPRESSED AS % INCREASE IN
MUTUAL CAPACITY IN 10 DAYS

TABLE 4

50 DAY

	WATER ABSORPTION OF CABLE SHEATHS			
	<u>50°C .050"</u>	<u>50°C .080"</u>	<u>70°C .050"</u>	<u>70°C .080"</u>
BUTYL POWER INSULATION	7%	6%	20%	10%
POLYETHYLENE	10	5	47	18
LAMINATED BUTYL-NEOPRENE	14	7	48	28
NEOPRENE SHEATH #2	60	34	88	66
NEOPRENE SHEATH #3	67	42	102	81
HYPALON	70	44	128	110
NEOP. LOW WATER ABS. SHEATH	82	54	108	95
NEOPRENE SHEATH #4	88	55	138	110
GRS SHEATH	90	70	126	102
NEOPRENE SHEATH #5	92	60	136	105
OIL BASE POWER INS.	110	82	140	114
RH-RW INSULATION	112	74	148	116
HYCAR SHEATH #2	116	111	136	138
NAT. RUBBER 60% SHEATH	122	88	172	132
HYCAR SHEATH #1	124	110	140	145
PVC SHEATH #1	142	116	168	156
PVC TW 90°C INSULATION	145	46	160	152
PVC SEMI-RIGID SHEATH #3	149	119	166	168
NAT. RUBBER 40% INS.	155	112	168	151
PVC SHEATH #2	168	130	175	156
PVC SHEATH #4	174	138	178	154
SILICONE 125°C INS.	214	196	266	252

DATA IS EXPRESSED AS % INCREASE IN
MUTUAL CAPACITY IN 50 DAYS

TABLE 5

LONG TERM

	WATER PENETRATION OF CABLE SHEATHS			
	50°C .050" <u>300 Days</u>	50°C .080" <u>300 Days</u>	70°C .050" <u>150 Days</u>	70°C .080" <u>150 Days</u>
BUTYL POWER INSULATION	12%	15%	29%	16%
POLYETHYLENE	23	11	56	18
LAMINATED BUTYL-NEOPRENE	26	20	66	46
NEOPRENE SHEATH #2	94	76	130	88
NEOPRENE SHEATH #3	116	101	160	116
HYPALON	122	98	198	160
NEOP. LOW WATER ABS SHEATH	121	90	134	111
NEOPRENE SHEATH #4	174	144	450	188
GRS SHEATH	136	115	166	134
NEOPRENE SHEATH #5	210	134	330	166
OIL BASE POWER INS.	160	112	206	160
RH-RW INSULATION	155	125	221	162
HYCAR SHEATH #2	168	165	212	195
NAT. RUBBER 60% SHEATH	202	150	238	175
HYCAR SHEATH #1	200	160	210	195
PVC SHEATH #1	175	158	218	204
PVC TW 90°C INS.	182	57	194	181
PVC SEMI-RIGID SHEATH #3	190	153	298	319
NAT. RUBBER 40% INS.	196	157	236	195
PVC SHEATH #2	200	147	204	172
PVC SHEATH #4	191	165	238	189
SILICONE 125°C INS.	328	286	495	438

DATA IS EXPRESSED AS % INCREASE IN
MUTUAL CAPACITY FOR PERIOD SHOWN

APPENDIX

Water absorption Test: IPCEA Specification S-19-81, Appendix N, Method GM. Sheets .070" \pm .010" 70°C

Water Permeability Test: Du Pont Method, dated 10/4/54, discs .030" \pm .003", Thwing - Albert cups. Catalogue 68-1. 75°F, 50% R.H.

Cable Penetration Test: See Figures 1 and 2. Sample containers were continuously maintained in ovens at designated temperatures for periods shown. Periodic capacitance measurements were made after cooling to room temperature, using L & N bridge. Samples were fabricated from 1 length #18/2 SV foundation:

GRS rubber insulation, U.L. grade - class 3, .016" wall 2 insulated conductors twisted to make 1 pair, employing dry jute fillers, to make round.

Rayon serve, 100% coverage, to .185" diameter.

Sheaths applied via laboratory extrusion, core pre-warmed to remove moisture, and fed to extruder from hot chamber.

Sheaths diameters - .285" and .345" \pm .005"

The laminated sheaths were built up by extruding the Butyl compound first, then the Neoprene, so that each comprised 50% of the total wall.

Rubber sheaths were vulcanized with ends sealed.

All samples were oven dried before initial test.

Great care was taken to avoid contamination and defects.

Samples were prepared uniformly. Tight fit in cover of polyethylene-lined immersion boxes was obtained. Ends were sealed with poured, hi-temp wax, through which conductor ends projected.

Materials applied as sheaths:

Butyl Power Insulation: Collyer ozone-resisting compound, IPCEA Appendix O.

Polyethylene: IPCEA Appendix P, black, weather-resistant, for line wire.

Laminated Butyl - Neoprene: Collyer compounds, Butyl Power Insulation (above) and Neoprene Sheath #5 (below).

Neoprene Sheath #2: Collyer compound, IPCEA Appendix K, black, CV type.

Neoprene Sheath #3: Collyer compound, IPCEA Appendix K, black, Lead Cure type.

Neoprene Sheath #4: Collyer compound, IPCEA Appendix K, white, all-purpose.

Neoprene Sheath #5: Collyer compound, IPCEA Appendix K, corona resisting, black.

Neoprene Low Water Absorbing Sheath: Collyer compound, IPCEA Appendix K, black.

Hypalon: Typical wire covering composition, black.

GRS Sheath: Collyer compound, U.L. class 6, IPCEA Appendix E, black, CV type.

RH-RW Insulation: Collyer compound, U.L., IPCEA Appendix C & N, GR-S.

Oil Base Power Insulation: Collyer compound, IPCEA Appendix D.

Natural Rubber 60% Sheath: Collyer compound, IPCEA Appendix F, Lead Cure type.

Natural Rubber 40% Insulation: Collyer compound, special purpose, black, CV type.

PVC Sheath #1: Polyvinyl thermoplastic available to industry, IPCEA Appendix J, also qualified as TW, low water absorbing, -40°C bend, high compression-cut resistance, black.

PVC Sheath #2: Polyvinyl thermoplastic available to industry, IPCEA Appendix J, low water absorbing, -50°C bend, black.

PVC Semi-Rigid Sheath #3: Polyvinyl thermoplastic available to industry, shipboard use, non-exhuding, black.

PVC Sheath #4: Polyvinyl thermoplastic available to industry, IPCEA Appendix J, -50°C bend, black.

PVC TW 90°C Insulation: Polyvinyl thermoplastic available to industry, IPCEA Appendix J, multi-purpose, -40°C bend, black.

Hycar Sheath #1: Compound designed for cable sheath, oil and water resistant polymer, black.

Hycar Sheath #2: Compound designed for cable sheath, oil resistant polymer, black.

Silicone 125°C Insulation: Compound available to industry, general purpose, white.